PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol 12(1): 1-6
https://doi.org/10.14719/pst.6118

HORIZON
e-Publishing Group

RESEARCH ARTICLE

Sustainable utilization of humanure-based bio-product for Marigold (*Tagetes erecta L*) production in Tropical India

P Kavya[1], P Jothimani[1*], M Maheswari[1], N Thavaprakaash[2], M Kavitha[3], G Sridevi[4] & SG Patil[5]

[1]Department of Environmental Science, Tamil Nadu Agricultural University, Coimbatore 641 003, India

[2]Coconut Research Station, Aliyar Nagar 642 101, Tamil Nadu, India

[3]Department of Vegetable Science, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[4]Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[5]Department of Physical Science and Information Technology, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

*Email: jothimani@tnau.ac.in

OPEN ACCESS

ARTICLE HISTORY
Received: 25 October 2024
Accepted: 28 October 2024
Available online
Version 1.0 : 21 January 2025
Version 2.0 : 25 January 2025

Check for updates

Additional information
Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

CITE THIS ARTICLE
Kavya P, Jothimani P, Maheswari M, Thavaprakaash N, Kavitha M, Sridevi G, Patil SG. Sustainable utilization of humanure-based bio-product for Marigold (*Tagetes erecta* L) production in Tropical India. Plant Science Today. 2025; 12(1): 1-6. https://doi.org/10.14719/pst.6118

Abstract

Ecological sanitation converts human waste into safe compost, known as humanure, offering a sustainable solution for managing faecal matter. This approach not only recycles nutrients but also reduces environmental pollution. Enriched humanure was prepared by mixing humanure, biochar and human urine in ratios of 1:1:1 and 1:1:1.5 and the mixture was enriched for 30 days. The pH, electrical conductivity (EC), nitrogen, phosphorous and potassium content of the bioinputs (humanure, biochar, human urine) alone and the enriched humanure (1:1:1 and 1:1:1.5) were characterized. To test the efficacy of the enriched humanure, field trials were conducted during the winter and summer seasons in Vridhachalam on marigolds (Hybrid-Bens tall) using a randomized block design with 11 treatments in three replications. Treatments included bioinputs alone, unenriched and enriched humanure, 50% enriched humanure + 50% recommended dose of fertilizer (RDF), RDF + farm yard manure (FYM) and FYM alone. Fertilizers and manures were applied based on the crop s' nitrogen requirement of 90: 90:75 kg/ha. The results showed significantly higher plant growth, flower yield (27.0 to 27.5 t/ha) and flower quality were recorded in the application of enriched humanure in the ratio of 1:1:1 followed by 1:1:1.5 compared to all other bio-inputs treatments and the control. Enriched humanure (1:1:1) proved the most effective treatment for improving marigold growth and yield.

Keywords

enriched humanure; flower quality; plant growth; yield

Introduction

Harnessing the potential of human excrement for crop production and soil rejuvenation is crucial in establishing a closed-loop nutrient cycle, garnering significant interest from the sanitation and agricultural sectors. Globally, on-site sanitation systems have surpassed traditional sewers as the predominant form of sanitation, which has vast opportunities for nutrient reclamation (1). However, challenges abound in the treatment and utilization phases within the sanitation service chain, as mismanagement can lead to system failures, jeopardizing public health by exposing individuals to enteric pathogens. On-site systems like pit latrines, septic tanks and container-based sanitation systems often face issues such as faecal sludge overflow during floods, inadequate emptying services, or improper disposal due to a lack of suitable facilities (Al-Hafiz, 2017)(2-6). Conventional sewers, though often perceived as superior, require meticulous design and management.

Many sewers worldwide lack connections to treatment plants, merely transferring contamination elsewhere (7). The sludge collected from these systems is typically disposed of by land or water application, incineration, agricultural use, or incorporation into construction materials (8,9). However, most disposal methods, including incineration, fail to fully capitalize on the valuable components of sludge, such as its moisture content, organic matter and nutrients. Ecological sanitation, also known as resource-oriented or sustainable sanitation, recognizes the utilization of nearly 1.0 billion tons of fecas generated annually (1), aiming to maximize the beneficial potential of human waste while minimizing environmental and health risks.

The preparation of enriched compost using human excreta comprising humanure and human urine has been practised for many years (10). The biochar, a pyrolyzed material prepared without oxygen, acts as an adsorbent of human urine and retains nutrients due to its large surface area and functional groups. Biochar is also used to prepare bio-compost alone or mixed with human urine (11). Using human urine in different ratios with humanure and biochar and incubating for about a month (enriched humanure) is one of the options for increasing the physical, chemical and biological properties besides reducing heavy metals, pathogens and pharmaceutical compounds, which needs scientific validation. In India, marigold (*Tagetes spp*.) has high market demand with an annual production of 1754 thousand metric tons (12, 13). Marigold flowers, particularly *Tagetes erecta* L., are primarily used for non-edible purposes, so the risk of human exposure to heavy metals and other contaminants through consumption is minimal (14). Therefore, marigold cultivation presents a viable solution for managing human excreta, offering a productive and sustainable means of utilizing this material. Furthermore, there is limited research examining the impact of human excreta on the growth and yield of marigold. Thus, the current study seeks to assess the efficacy of enriched human manure (enriched humanure) on marigold plant growth and yield characteristics.

Materials and Methods

Manure preparation

Humanure and urine were collected from Ecosan toilets in various primary schools in Cuddalore District. The biochar used in the study was sourced locally from Cuddalore and was made from the wood of *Prosopis* trees. These trees are abundant and often considered waste. *Prosopis* plants are known to lower the groundwater table, so the Tamil Nadu government has been actively removing them from land to help preserve water resources. The removed wood is then converted into biochar and repurposed for agricultural applications. The unenriched humanure was prepared by mixing humanure, biochar and human urine (1:1:1 and 1:1:1.5 ratios) just before application to the field. The enriched humanure was prepared by mixing humanure, biochar and human urine at 1:1:1 and 1:1:1.5 ratios, respectively. The mixture was kept for 30 days for incubation and used for crop cultivation. The nutrient content of the bio-inputs (manures) is in Table 1. Manure pH and Electrical conductivity (EC) were determined in a 1:5 (manure: water) solution (w/v) (15). Total nitrogen was through the alkaline permanganate method. Total phosphorus was estimated through the ammonium molybdate colourimetric method and ammonium acetate extract method with a flame photometer to assess the Total Potassium (16-18). *Escherichia coli* presence in manure samples was also tested using the most popular number (MPN) test and salmonella typhi was estimated using the culture method (19, 20).

pH

The pH of humanure was found to be 8.01, indicating a slightly alkaline nature. Biochar was more neutral, with a pH of 7.43, while human urine had a pH of 7.89. After combining and enriching the materials, the pH of the unenriched mixture remained at 8.01. The enriched humanure mixtures showed slightly higher pH levels, with the 1:1:1 ratio showing a pH of 8.23 and the 1:1:1.5 ratio showing 8.26, indicating a consistent mildly alkaline environment.

Electrical conductivity (EC)

Humanure exhibited an electrical conductivity (EC) of 1.74 dS/m, which indicates its ability to conduct electrical current, suggesting the presence of salts. Biochar had a lower electrical conductivity of 0.86 dS/m, while human urine showed the highest electrical conductivity at 5.52 dS/m, reflecting its higher salt content. After mixing, the electrical conductivity values for the enriched humanure (1:1:1and 1:1:1.5) were slightly increased to 1.93 dS/m and 2.08 dS/m, respectively, compared to the unenriched mixture at 1.82 dS/m and 1.99 dS/m.

Nutrient content (Nitrogen, phosphorus and Potassium)

Total nitrogen (N)

Humanure had a high nitrogen content at 3.50%, while biochar and human urine contributed 0.74% and 1.28%, respectively. After enrichment, the nitrogen content of the mixture increased slightly, reaching 3.97% and 4.05% for the 1:1:1 and 1:1:1.5

Table 1. Characteristics of bio-inputs materials and enriched humanure (mean ± SD) used in the present study

Parameters	Humanure	Biochar	Human Urine	Enriched humanure	
				1:1:1	1:1:1.5
pH	8.01 ± 0.14	7.43 ± 0.19	7.89 ± 0.21	8.23 ± 0.01	8.26 ± 0.11
EC (dS/m)	1.74 ± 0.05	0.86 ± 0.04	5.52 ± 0.12	1.93 ± 0.01	2.08 ± 0.03
Macro nutrients					
Total nitrogen (%)	3.50 ± 0.20	0.74 ± 0.06	1.28 ± 0.02	3.97 ± 0.08	4.05 ± 0.06
Total phosphorus (%)	1.72 ± 0.15	0.20 ± 0.05	1.56 ± 0.11	2.12 ± 0.02	2.15 ± 0.03
Total Potassium (%)	3.45 ± 0.19	8.40 ± 1.03	0.19 ± 0.01	4.15 ± 0.01	4.20 ± 0.05
Pathogens					
Total Coliforms	Nil	Nil	Nil	Nil	Nil
Salmonella typhi	Nil	Nil	Nil	Nil	Nil

ratios, respectively.

Total phosphorus (P)

Humanure contained 1.72% phosphorus, biochar had a much lower value at 0.20% and human urine provided 1.56%. After enrichment, the phosphorus content increased to 2.12% and 2.15% for the enriched mixtures, compared to 1.85% and 1.89% for the 1:1:1 and 1:1:1.5 ratios, respectively, in the unenriched form.

Total Potassium (K)

Humanure had a potassium content of 3.45%, biochar had a significantly higher value at 8.40%, while human urine contributed only 0.19%. Enriched humanure showed further improvement, with the potassium levels reaching 4.15% and 4.20% in the enriched mixtures compared to the unenriched form.

Pathogens

Pathogen testing for total coliforms and *Salmonella typhi* showed no harmful bacteria in humanure, biochar, human urine, or enriched or unenriched humanure mixtures. This indicates that the composting and enrichment processes successfully eliminated potential pathogens, making the manures safe for agricultural use.

Field study

Study location

A field trial was conducted at the Regional Research Station of Tamil Nadu Agricultural University in Vridhachalam (coordinates: 11°31'46"N, 79°21'31"E). The first trial occurred from January to May 2023. Throughout this period, the maximum monthly temperatures ranged from 30.0 °C to 35.8 °C, while the minimum temperatures varied between 20.0°C and 24.6 °C. The total rainfall recorded during this time was 15 mm. For validation, a second trial was initiated in May and continued until September in the same field. During this phase, the maximum temperature increased, ranging from 23 °C to 32 °C. Rainfall during this period was higher, averaging between 81 mm and 135 mm. The soil of the experimental field is red lateritic, which comes under the Lalpettai series. Before planting, soil samples (15 cm depth) were collected to test the physical and chemical characteristics. The characteristics of the experimental field soil are given in Table 2. Soil pH and Electrical conductivity (EC) were determined in a 1:2.5 (soil: water) solution (w/v). At the same time, the organic carbon (OC) was estimated through the chromic acid wet digestion method, available nitrogen (N) through the alkaline permanganate method and available phosphorus (P) was assessed through the Bray method (15,16,21,22). The ammonium acetate extract method with a flame photometer was used to calculate the available Potassium (K) (18). The soil micronutrients, namely iron (Fe), copper (Cu), manganese (Mn) and zinc (Zn), were determined through the DTPA extractant method (23). All analyses were conducted in the Department of Environmental Science laboratory, Tamil Nadu Agricultural University, Coimbatore.

Table 2. Initial characteristics of experimental field soil

S.No	Parameters	Value
1	pH (1: 2.5)	6.84 (Neutral)
2	EC (dS/m)	0.45 (Non-saline)
3	Organic carbon (%)	0.27 (Low)
4	Available nitrogen (kg/ha)	245 (Low)
5	Available phosphorus (kg/ha)	12.32 (medium)
6	Available potassium (kg/ha)	156 (medium)
7	Exchangeable calcium (cmol (p^+)/kg)	1.58
8	Exchangeable magnesium (cmol (p^+)/kg)	0.82
9	Exchangeable sodium (cmol (p^+)/kg)	0.51
10	Exchangeable Potassium (cmol (p^+)/kg)	0.45
11	Iron (mg/kg)	28.01(sufficient)
12	Copper (mg/kg)	1.90 (sufficient)
13	Zinc (mg/kg)	5.32 (sufficient)
14	Manganese (mg/kg)	24.51(sufficient)

The pH of the soil sample was 6.8 and electrical conductivity (EC) was 0.45 dS/m. The available NPK contents were 245, 12.32 and 156 kg/ha, respectively and the organic carbon was 0.27 percentages. The soil was low in nitrogen content and medium in phosphorus and potassium contents. The micronutrients such as Fe, Cu, Zn and Mn were 28.01, 1.90, 5.32 and 24.51 mg/kg, respectively.

Field experimental details

Marigold (*Bens tall-hybrid*) seedlings were purchased from a nearby nursery at Vridhachalam and transplanted. The experimental field consists of 11 treatments and is replicated thrice with the field layout made using a randomized block design. The treatment details are given in Table 3. For the experiment, the marigold crop (Hybrid-Bens Tall) was spaced at 90 cm × 22.5 cm and the recommended fertilizer dose was 90:90:75 NPK kg/ha.

Manure application

Other bio-inputs and enriched humanure were applied based on the nitrogen content of each type of manure, as shown in Table 3. The manure was manually applied before transplanting and manually incorporated with soil. Standard cultivation practices for marigolds were followed under the 2020 guidelines from Tamil Nadu Agricultural University (TNAU) (24). After 30, 60 and 110 days after transplanting (DAT), plant growth parameters like plant height (cm), number of branches per plant and stem diameter (cm) were analyzed. Besides the flower quality parameters like the flower diameter (cm), flower stalk length (cm), individual flower weight (g), number of flowers per plant, flower yield (t/ha), shelf life (days) and xanthophyll content (mg100 g) were analyzed (25).

Statistical analysis

When the treatment effects were substantial, the randomized block design was used. SPSS statistical software was used for all statistical analyses (SPSS Inc, Chicago, IL). This analysis was conducted using the R tool (Version 3.5.1). Differences at the $P < 0.05$ level were regarded as statistically significant.

Results and Discussion

Effect of enriched humanure on plant growth parameters in marigold crop

Plant height

Plant height noted 30, 60 and 110 DAT shown in Fig. 1. Findings from this study indicated a significant increase in plant height during 110 DAT, with the maximum plant height of 59.25 cm observed in enriched humanure (T_6-1:1:1) followed closely by

Table 3. Description of treatments

Treatment	Type of manure and fertilizers	Recommended dose of fertilizer (kg/ha) (N: P_2O_5: K_2O)
T_1	Humanure alone	2571 kg/ha
T_2	Biochar alone	12,162 kg/ha
T_3	Human urine alone	7500 l /ha
T_4	Unenriched humanure (humanure + biochar + human urine -1.0:1.0:1.0 ratio)	2535 kg/ha
T_5	Unenriched humanure (humanure + biochar + human urine - 1.0:1.0:1.5 ratio)	2785 kg/ha
T_6	Enriched humanure (humanure + biochar + human urine -1.0:1.0:1.0 ratio)	2267 kg/ha
T_7	Enriched humanure (humanure + biochar + human urine - 1.0:1.0:1.5 ratio)	2222 kg/ha
T_8	50% through enriched humanure (humanure + biochar + human urine - 1.0:1.0:1.0 ratio) + 50% through RDF	1134 kg/ha + 45:45:37.5 (N:P:K) kg/ha
T_9	50% through enriched humanure (humanure + biochar + human urine - 1.0:1.0:1.5 ratio) + 50% through RDF	1111 kg ha^{-1} + 45:45:37.5 (N:P:K) kg/ha
T_{10}	100% RDF+ FYM	90:90:75 (N:P:K) kg/ha
T_{11}	FYM alone	18000 kg/ha

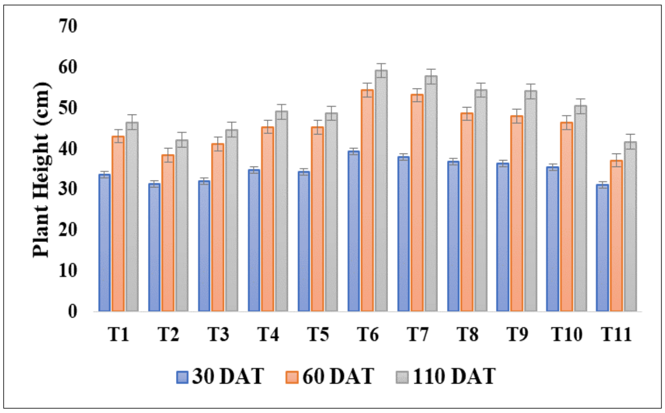

Fig. 1. Effect of enriched humanure on plant height of Marigold. The error bars indicate the standard deviation values (Two seasons mean data).

enriched humanure (T_7-1:1:1.5), which showed comparable results. The lowest plant height of 41.76 cm was observed with the sole application of FYM (T_{11}-control). This may be due to readily available nutrients in the enriched humanure for plant uptake. The increase in plant height with the application of enriched humanure in this study underscores its positive impact on marigold cultivation. These results confirm that sewage sludge application significantly improved shoot and root length in marigolds (25). Similarly, faecal amendments increased plant height and biomass by a median value of 24% and 82%, respectively (26).

Number of branches and stem diameter

Similarly, a significant increase was noted in number of branches and stem diameter in the application of enriched humanure in marigold crop (Fig. 2). During 110 DAT the highest number of branches per plant (28.33) and stem diameter (6.33 cm) were also recorded in the treatment enriched humanure (T_6-1:1:1), followed closely by enriched humanure (T_7-1:1:1.5), which showed comparable results. The lowest number of branches per plant (13.15) and stem diameter (3.61 cm) were also recorded with the sole application of FYM (T_{11}-control) during 110 DAT. This may be due to readily available nutrients in the enriched humanure for plant uptake. These findings are consistent with a study that showed faecal amendments increased plant height and biomass by 24% and 82%, respectively (26).

Yield parameters and flower quality of marigold

The effect of enriched humanure on marigold yield and flower quality parameters has been shown in Table 4 and Fig. 3.

Early flowering

This current study highlighted a significantly shorter time to first flowering was observed (27 days) in enriched humanure (T_6-1:1:1) and enriched humanure (T_7-1:1:1.5), the late flowering (31 days) was observed with the sole application of FYM (T_{11}-control) followed by T_2 (biochar alone). The earlier flowering observed in this study was due to the increased metabolite uptake by the shoots and roots of marigolds, a phenomenon previously noted in sunflowers amended with organic fertilizers and marigolds amended with sewage sludge (25, 27).

Dry matter production

The maximum dry matter production of 297.76 kg/ha and 295.45 kg/ha was observed with enriched humanure (T_6-1:1:1) and enriched humanure (T_7-1:1:1.5), respectively, which showed comparable results. The lowest dry matter production, 262.09 kg/ha,was observed with the sole application of FYM (T_{11}-control). This may be due to a slow and steady release of nutrients. This balanced nutrient supply helps sustain vegetative growth and results in more significant biomass accumulation.

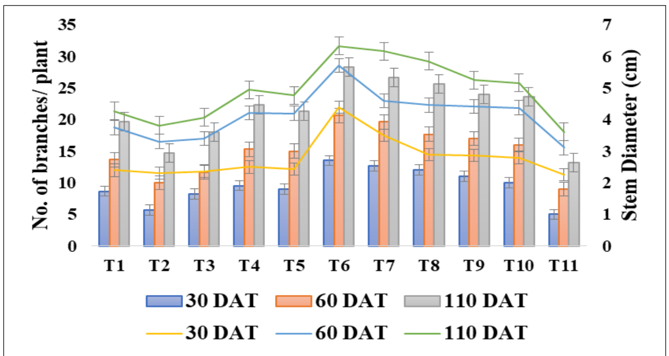

Fig. 2. Effect of enriched humanure on number of branches per plant (bar graph) and stem diameter (line graph) on Marigold. The error bars indicate the standard deviation values (Two seasons mean data).

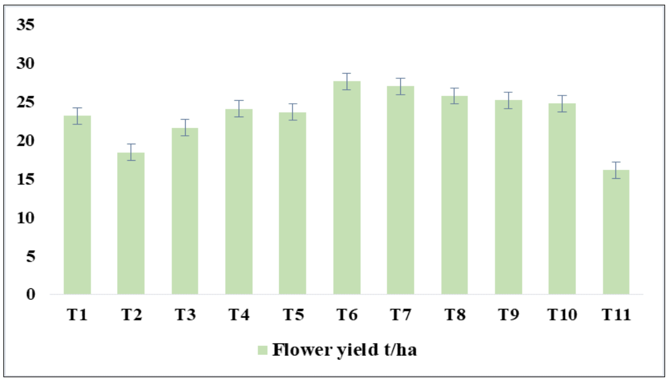

Fig. 3. Effect of enriched humanure on yield of Marigold (Two seasons mean data).

Table 3. Description of treatments

Treatments	Days to flowering (Days)	Dry matter production (kg/ha)	Flower Diameter (cm)	Flower stalk length (cm)	Single flower weight (g)	No. of flowers per plant	Flower yield (t/ha)	Shelf life (days)	Xanthophyll content (mg/100 g)
T_1	30 ± 1.12	271.10 ± 12.54	17.47 ± 2.64	5.82 ± 0.79	17.70 ± 1.06	27.00 ± 1.05	23.15 ± 1.21	4.0 ± 0.21	345.58 ± 10.20
T_2	31 ± 1.54	265.35 ± 15.97	15.82 ± 1.99	5.07 ± 0.49	14.88 ± 1.60	24.67 ± 1.06	18.45 ± 1.31	3.2 ± 0.31	325.07 ± 9.45
T_3	30 ± 1.35	268.43 ± 13.15	16.93 ± 2.21	5.33 ± 0.31	16.03 ± 1.29	26.00 ± 1.12	21.65 ± 1.64	3.8 ± 0.40	330.76 ± 8.06
T_4	28 ± 1.54	278.22 ± 13.15	19.56 ± 3.10	6.53 ± 0.46	18.73 ± 1.64	31.00 ± 1.64	24.10 ± 1.16	4.7 ± 0.29	361.57 ± 10.33
T_5	29 ± 1.77	276.42 ± 15.62	18.85 ± 2.79	6.50 ± 0.97	18.52 ± 1.97	30.33 ± 1.94	23.67 ± 1.16	4.3 ± 0.14	354.30 ± 10.54
T_6	27 ± 1.36	297.76 ± 14.19	23.68 ± 1.06	8.46 ± 0.23	24.39 ± 1.21	38.33 ± 1.63	27.65 ± 1.03	6.0 ± 0.19	390.10 ± 10.88
T_7	27 ± 1.51	295.45 ± 11.05	22.65 ± 2.41	7.42 ± 0.61	23.20 ± 1.06	37.00 ± 1.06	27.00 ± 1.13	5.8 ± 0.18	389.40 ± 10.49
T_8	28 ± 1.10	286.52 ± 10.61	20.45 ± 2.91	6.87 ± 0.79	20.95 ± 1.49	35.38 ± 1.49	25.76 ± 1.64	5.5 ± 0.16	380.71 ± 9.33
T_9	28 ± 1.09	283.32 ± 11.66	20.31 ± 2.05	6.80 ± 0.34	20.75 ± 1.64	35.33 ± 1.06	25.18 ± 1.06	5.2 ± 0.20	377.94 ± 10.78
T_{10}	29 ± 1.54	280.11 ± 10.94	19.14 ± 1.09	6.33 ± 0.26	19.26 ± 1.06	32.00 ± 1.18	24.78 ± 1.69	5.0 ± 0.17	366.58 ± 10.09
T_{11}	31 ± 1.77	262.09 ± 11.19	15.73 ± 1.97	4.88 ± 0.66	14.45 ± 1.33	24.00 ± 1.94	16.13 ± 1.27	3.0 ± 0.19	314.29 ± 10.88
SE.d	0.55	0.72	0.71	0.33	0.47	0.79	0.49	0.18	8.84
CD (0.05)	1.14	1.51	1.48	0.69	0.98	1.66	1.02	0.39	18.45

Note: Data is mean ± SD. T_1 - humanure alone, T_2 - biochar alone, T_3 - human urine alone, T_4 -unenriched humanure (1:1:1), T_5 - unenriched humanure (1:1:1.5),T_6 - 100% through enriched humanure (1:1:1), T_7 - 100% through enriched humanure (1:1:1.5), T_8 - 50% through enriched humanure (1:1:1) + 50% through recommended dose of fertilizer, T_9 - 50% through enriched humanure (1:1:1.5) + 50% through recommended dose of fertilizer, T_{10} - 100% through RDF + FYM and T_{11} - FYM alone.

For example, studies have shown that sewage sludge increased marigold biomass and enhanced shoot and root development by improving nutrient availability (25).

Flower diameter and stalk length

The maximum flower diameter of 23.68 cm and flower stalk length of 8.46 cm were recorded in the treatment enriched humanure (T_6-1:1:1) and followed by enriched humanure (T_7-1:1:1.5) and the lowest flower diameter of 15.73 cm and flower stalk length of 4.88 cm was recorded with the sole application of FYM (T_{11}-control). The improved nutrient content in enriched humanure likely contributes to a steady release of macro and micronutrients to plants. Notably, nitrogen (N) plays a crucial role as an essential element in amino acids, nucleotides, nucleic acids, various coenzymes, cytokinins and alkaloids. This nitrogen availability may enhance cell elongation, expansion and proliferation, which could increase flower diameter and stalk length in marigold flowers. These findings are consistent with those reported in research (28).

Single flower weight and number of flowers per plant

Enriched humanure (T_6-1:1:1) had the maximum single flower weight of 24.39 g and number of flowers per plant of 38.33 no s' followed by Enriched humanure (T_7-1:1:1.5). The lowest single flower weight (14.45 g) and the number of flowers per plant (24.00 nos') was observed with the sole application of FYM (T_{11}-control). This improvement with enriched humanure could be attributed to the production of salicylic acid (SA), a key plant hormone involved in stress regulation and flower development. Studies have demonstrated that enriched organic amendments in marigolds and roses enhance plant SA production (25, 29).

Flower yield

Enriched humanure in a ratio of 1:1:1 and 1:1:1.5 applied plots significantly increased the flower yield of 27.65 t/ha and 27.00 t/ha respectively (Fig. 3.) and the lowest flower yield of 16.13 t/ha was recorded with the sole application of FYM (T_{11}-control). This may be because the enriched humanure supplies a consistent and balanced flow of nutrients, which helps improve the plant s' overall nutrition. This steady nutrient supply allows marigold plants to produce more biomass and as a result, they photosynthesize more. With more effective photosynthesis, the plants generate more energy for flower production, increasing the number and size of flowers. This slow-release feature also minimizes nutrient loss through leaching, making the nutrient use more efficient and sustainable over time. These findings are consistent with research conducted on marigolds (25).

Shelf life

Enriched humanure significantly increased the shelf life compared to other treatments. Enriched humanure 1:1:1 and 1:1:1.5 applied plots recorded a 6-day shelf life and the lowest shelf life of 3.03 was recorded with the sole application of FYM (T_{11}-control). The increased shelf life may be due to cytokinin production by enriched humanure. Cytokinin helps to delay the degradation of fruits and flowers (30).

Xanthophyll content

Xanthophylls, natural pigments offering an alternative to synthetic dyes as food colourants due to their non-toxic nature, were also studied. Results revealed that the application of enriched humanure significantly increased the xanthophyll content, with a maximum of 390.1 mg/100g observed with the application of enriched humanure (T_6-1:1:1) and followed by enriched humanure (T_7-1:1:1.5) (389.4 mg/100 g), which showed similar results. This may be due to available macro and micronutrients in enriched humanure. Enriched manures increase carotenoid synthesis, including xanthophyll, by providing essential nutrients and improving soil health, ultimately enhancing the plant's physiological process (31).

Conclusion

The findings of this study suggest that enriched humanure can be effectively utilized in marigold cultivation, leading to significant improvements in growth, yield and flower quality. The most favourable results were obtained with enriched humanure at a 1:1:1 ratio. However, further research is needed to evaluate its suitability for other floricultural and horticultural crops. Investigating the residual effects of enriched humanure is crucial to determine how long the released nutrients persist in the soil. Enriched humanure promotes nutrient recycling and offers the potential to reduce dependency on costly chemical fertilizers, making it a promising and sustainable option for bio-fertilization in agriculture.

Acknowledgements

The authors thank Tamil Nadu Agricultural University for providing the necessary support and facilities to perform this work.

Authors' contributions

PK conducted the experiment and wrote the original draft, PJ helps data curation supervision and MM checked the data and supervision. NT helped with conceptualization, supervision & editing. MK and GS helped with the editing and SGP helped with the statistical data analysis.

Compliance with ethical standards

Conflict of interest: Author's do not have any conflict of interest to declare

Ethical issues: None

References

1. Berendes DM, Yang PJ, Lai A, Hu D, Brown J. Estimation of global recoverable human and animal faecal biomass. Nat Sustain. 2018;1 (11):679-85. https://doi.org/10.1038/s41893-018-0167-0
2. Sherpa AM, Koottatep T, Zurbrügg C, Cissé G. Vulnerability and adaptability of sanitation systems to climate change. J Water Clim Chang. 2014;5(4):487-95. https://doi.org/10.2166/wcc.2014.003
3. Cookey PE, Kugedera Z, Alamgir M, Brdjanovic D. Perception management of non-sewered sanitation systems towards scheduled faecal sludge emptying behaviour change intervention. Humanit Soc Sci Commun. 2020;7(1):1-20. https://doi.org/10.1057/s41599-020-00662-0
4. Nakagiri A, Kulabako RN, Nyenje PM, Tumuhairwe JB, Niwagaba CB, Kansiime F. Performance of pit latrines in urban poor areas: A case of Kampala, Uganda. Habitat Int. 2015;49:529-37. https://doi.org/10.1016/j.habitatint.2015.07.005
5. Prasad CS, Ray I. When the pits fill up: (in) visible flows of waste in urban India J Water Sanit Hyg Dev. 2019; 9(2):338-47. https://doi.org/10.2166/washdev.2019.153
6. Koottatep T, Taweesan A, Kanabkaew T, Polprasert C. Inconvenient truth: unsafely managed fecal sludge after achieving MDG for decades in Thailand. J Water Sanit Hyg Dev. 2021;11(6): 1062-70. https://doi.org/10.2166/washdev.2021.118
7. Orner KD, Mihelcic JR. A review of sanitation technologies to achieve multiple sustainable development goals that promote resource recovery. Environ Sci (Camb). 2018;4(1):16-32. https://doi.org/10.1039/c7ew00195a
8. Collivignarelli MC, Canato M, Abba A, Miino MC. Biosolids: what are the different types of reuse? J Clean Prod. 2019;238:117844. https://doi.org/10.1016/j.jclepro.2019.117844
9. Ding A, Zhang R, Ngo HH, He X, Ma J, Nan J, Li G. Life cycle assessment of sewage sludge treatment and disposal based on nutrient and energy recovery: A review. Sci Total Environ.2021;769:144451. https://doi.org/10.1016/j.scitotenv.2020.144451
10. Rose C, Alison P, Bruce J, Elise C. The characterization of feces and urine: a review of the literature to inform advanced treatment technology. *Crit Rev Environ Sci Technol.* 2015;45:1827-79. https://doi.org/10.1080/10643389.2014.1000761
11. Panigrahi G. Studies on enrichment of biochar with human urine and Its effect on soil properties and crop growth. M.Sc [Thesis]. Bengaluru: University of Agricultural Sciences; 2013. Available from: https://krishikosh.egranth.ac.in/handle/1/85334
12. Kumari, Sonika, Kothari R., Kumar V, Kumar P, Tyagi W. Kinetic assessment of aerobic composting of flower waste generated from temple in Jammu, India: a lab-scale experimental study. Environ Sustain. 2021;4:393-400. https://doi.org/10.1007/s42398-021-00179-5
13. Kaur H, Singh J, Singh B. Importance and Prospects of Marigold. Just Agric. 2021;2: 1-5.
14. Greinert AMD, Węclewski S. Phytotoxic effects of sewage sludges on decorative plants. Pol J Environ Stud. 2009;6:41-8.
15. Jackson M. Soil chemical analysis. New Delhi: Pentice Hall of India Pvt. Ltd.; 1973
16. Subbiah BV, Asija GL. A rapid procedure for the estimation of available nitrogen in soils. Curr Sci. 1956;25:258-60.
17. Olsen SR, Cole CV, Watanabe FS. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. US Department of Agriculture Circular. 1954; 939.
18. Stanford G, English L. Use of the flame photometer in rapid soil tests for K and Ca. Agron J. 1949;41:446-7. https://doi.org/10.2134/agronj1949.00021962004100090012x
19. American Public Health Association. Standard methods for the examination of water and wastewater. 21st ed, American Public Health Association; 2005.
20. International Organization for Standardization. Microbiology of the food chain, Horizontal method for the detection, enumeration and serotyping of Salmonella- Part 1: Detection of *Salmonella spp.* International Organization for Standardization. 2017; 6579-1.
21. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 1934;37(1):29-38. https://doi.org/10.1097/00010694-193401000-00003
22. Bray RH, Kurtz LT. Determination of total, organic and available forms of phosphorus in soils. Soil Sci. 1945;59(1):39-46. https://doi.org/10.1097/00010694-194501000-00006
23. Lindsay W L, Norvell W. Development of a DTPA soil test for zinc, iron, manganese and copper. Soil Sci Soc Am J. 1978;42(3):421-8. https://doi.org/10.2136/sssaj1978.03615995004200030009x
24. Directorate of Horticulture and Plantation Crops. Crop Production Guide [internet]. Coimbatore:TNAU; 2020 [cited 2024 Oct 10]. Available from: https://agritech.tnau.ac.in
25. AL-Huqail AA, Kumar P, Abou Fayssal S, Adelodun B, Širić I, Goala M, Eid EM. Sustainable use of sewage sludge for marigold (*Tagetes Erecta* L.) cultivation: experimental and predictive modeling studies on heavy metal accumulation. Horticulturae.2023;9(4):447. https://doi.org/10.3390/horticulturae9040447
26. Allen K, Rodríguez López EL, Banwart SA, Evans B. A Systematic review of the effects of fecal sludge derived amendments on crop growth and soil health. ACS ES T Engin.2023;3:746-61. https://doi.org/10.1021/acsestengg.2c00438
27. Alzamel NM, Taha EM, Bakr AA, Loutfy N. Effect of organic and inorganic fertilizers on soil properties, growth yield and physiochemical properties of sunflower seeds and oils. Sustainability. 2022;14(19):12928. https://doi.org/10.3390/su141912928
28. Arulmani R, Sellamuthu K.M ,Maragatham S, Senthil A, Thamaraiselvi S.P, Anandham R, Malathi P, Sridevi G. Yield and quality of beetroot to soil test crop response (STCR)-integrated plant nutrient system (IPNS) based fertilizer prescription in Ultisols of Western Ghats of Tamil Nadu, India. Plant Sci Today. 2024;11 (4):91-7. https://doi.org/10.14719/pst.4623
29. Zahid A, Yike G, Kubik S, Ramzan M, Sardar H, Akram MT, Skalicky M. Plant growth regulators modulate the growth, physiology and flower quality in rose (*Rosa hybirda*). J King Saud Univ Sci. 2021;33 (6):101526. https://doi.org/10.1016/j.jksus.2021.101526
30. Ming X, Tao YB, Fu Q, Tang M, He H, Chen MS, Xu ZF. Flower-specific overproduction of cytokinins altered flower development and sex expression in the perennial woody plant *Jatropha curcas* L. Int J Mol Sci. 2020;21(2):640. https://doi.org/10.3390/ijms21020640
31. Chen J, Zhang X. The role of enriched organic manure in improving plant pigmentation and stress tolerance. J Agric Food Chem. 2021;69(10):1523-34.